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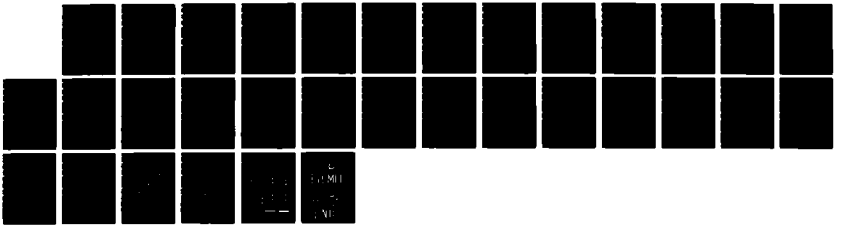

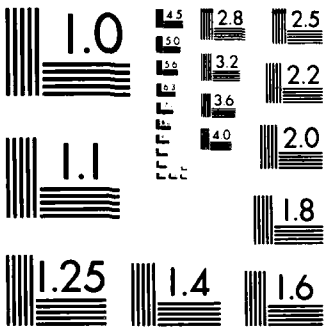

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INFLUENCE OF ERYTHROCYTHEMIA ON BLOOD VOLUME AND THERMOREGULATION DURING EXERCISE-HEAT STRESS

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Abbreviated Title: Erythrocythemia and Exercise-Heat Stress

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ABSTRACT

We studied the effects of autologous erythrocyte infusion on blood volume and thermoregulation during exercise in the heat. Using a double blind design, nine unacclimated male subjects were infused with either 700 ml of a NaCl-glucose-phosphate solution containing a ~60% hematocrit (n=6, reinfusion) or 700 ml of this solution only (n=3, saline). A heat stress test (HST) was attempted approximately 2 wk pre- and 48 h post-infusion during the late spring months. After 30 min of rest in a 20°C antechamber, the HST consisted of a 120-min exposure (two repeats of 15-min rest and 45-min treadmill walking) in a hot (35°C, 45% rh) environment while euhydrated. Red cell volume (RCV, ^{51}Cr) and plasma volume (PV, ^{125}I) were measured 24-h before each HST, and maximal oxygen uptake ($\dot{V}O_2$ max) was measured 24-h after each HST. Generally, no significant effects were found for the saline group. For the reinfusion group, RCV (11%, $P < 0.01$) and $\dot{V}O_2$ max (11%, $P < 0.05$) increased after infusion, and the following observations were made: (1) the increased RCV was associated with a reduction in PV to maintain the same blood volume as during the pre-infusion measurements; (2) erythrocythemia reduced total circulating protein, but did not alter F-cell ratio, plasma osmolality, plasma protein content, or plasma lactate at rest or during exercise-heat stress; (3) erythrocythemia did not change the volume of fluid entering the intravascular space from rest to exercise-heat stress; and (4) erythrocythemia reduced heat storage during exercise-heat stress.

Index Terms: blood "doping", blood reinfusion, euhydration, heat storage, plasma volume, red cell volume, temperature regulation

INTRODUCTION

Buick et al. (4) conclusively demonstrated that acute erythrocythemia improves an individual's submaximal and maximal exercise performance in a comfortable temperature environment. Subsequent investigators have confirmed these findings in comfortable temperature normoxic (17, 18, 19) as well as hypoxic (19) environments. These studies used erythrocyte freeze-preservation (30, 31) for autologous reinfusion (at least 2 units) following the re-establishment of normocythemia (12, 13). The physiological mechanism believed primarily responsible for the improved exercise performance is increased arterial oxygen content (12, 13); however, it is possible that blood volume expansion may also contribute to these ergogenic effects (17, 27). Blood volume measurements (from independent measurements of plasma and red cell volume) have not been obtained during previous erythrocyte reinfusion studies, but Kanstrup and Ekblom (17) have measured red cell volume (^{51}Cr). Based on red cell volume measurements, these investigators calculated that blood volume had increased after erythrocyte reinfusion (17). Likewise, two recent animal studies (one measured only plasma volume and the other measured both red cell and plasma volume) also support the concept of an expanded blood volume after erythrocyte infusion (27, 33).

The influence of acute erythrocythemia on thermoregulatory responses during exercise-heat stress has not been studied. However, there are several reasons why erythrocyte infusion may be beneficial to individuals performing exercise in the heat. During exercise-heat stress, core temperature increases as a consequence of the metabolic and environmental heat load. To minimize these core temperature changes, vasomotor adjustments occur to increase skin blood flow, and dilate superficial veins. These adjustments facilitate sensible and

insensible heat loss and also displace a portion of the central blood volume to the cutaneous vasculature. Under conditions of combined exercise-heat stress, a competition may exist between the circulatory requirements of metabolically active skeletal muscle and the cutaneous vasculature (20, 22). Eventually this competition can compromise cardiac output as well as heat dissipation (20, 22). Therefore, an intervention which increases arterial oxygen content as well as blood volume might improve exercise-heat performance. Increased arterial oxygen content will enable a greater arteriovenous oxygen difference to maintain aerobic metabolism, and an expanded blood volume will provide a defense against peripheral pooling and subsequent hypovolemia. Finally, some investigators believe that during exercise core temperature responses are coupled to relative exercise intensity (7, 21). Erythrocyte reinfusion has been shown to increase maximal aerobic power (4, 17, 18, 19, 29); therefore, the relative exercise intensity and thus core temperature might be lower during exercise at a given oxygen uptake level.

In the present study, we examined the effects of erythrocyte reinfusion on blood volume and thermoregulation during exercise in the heat. The information gathered should help clarify physiological mechanisms responsible for the ergogenic effects of erythrocyte reinfusion.

METHODS

Subjects. Nine fit male volunteers from the 10th Special Forces Group (Ft. Devens, MA) participated in this investigation. Five additional subjects volunteered and had phlebotomies, but were transferred during the subsequent seven months or were unavailable for testing. These subjects were all members of the same team and therefore were exposed to similar physical activity,

environmental extremes and diet throughout the study. The subjects were divided into a reinfusion and a saline group. The reinfusion group (n=6) had a mean (± SD) age of 30 ± 7 yr (including the 43 yr old platoon sargeant), weight of 79 ± 9 kg, surface area-to-mass ratio of 254 ± 14 $cm^2 \cdot kg^{-1}$, and percent body fat of 15 ± 5. The saline group (n=3) had a mean (±SD) age of 22 ± 1 yr, weight of 83 ± 20 kg, surface area-to-mass ratio of 246 ± 26 $cm^2 \cdot kg^{-1}$, and percent body fat of 15 ± 4. Subjects were informed of the purpose and potential risks of the study, the extent of their involvement, and their right to terminate participation at will. Each signed a statement of informed consent.

Protocol. During the late fall and early winter months, two units of blood were removed by phlebotomy from each subject. A minimum of six weeks separated the removal of each blood unit. During the subsequent spring months, the experimental portion of the study was completed. Initially, the subjects were familiarized with the test procedures, their percent body fat was determined by hydrostatic weighing, and they completed practice exercise tests. Several days prior to pre-testing, the subjects' red cell volume and plasma volume were measured. The pre-testing included a maximal aerobic power test and a heat stress test, which were completed on separate days. Approximately two weeks (range 10 -17 days) later each subject received an infusion. The reinfusion group received 700 ml of a sodium chloride-glucose-phosphate solution containing a ~60% Hct (autologous erythrocytes), whereas the saline group received 700 ml of the sodium chloride-glucose-phosphate solution only. Red cell volume and plasma volume was measured 24-h post-infusion, the HST was attempted 48-h post-infusion, and a maximal aerobic power test was completed 72-h post-infusion.

Blood storage, infusion, as well as red cell volume and plasma volume measurements were conducted at the Naval Blood Research Laboratory. After

each phlebotomy, the blood was separated into its red cell and plasma components, and the red cells were frozen with 40% w/v glycerol and stored at -80°C (30, 31). For the reinfusion group, approximately 700 ml of autologous erythrocytes in a sodium chloride-glucose-phosphate solution were administered over a 1-hour period. The frozen cell component was thawed and washed to reduce the glycerol concentration to less than 1%. The red blood cell oxygen transport function was determined from the red blood cell 2,3 DPG, ATP and in vitro P_{50} measurements (32). For the saline group, a similar time period was used to administer the sodium-chloride-glucose-phosphate solution. During the infusion sessions, the subjects were blindfolded and wore earphones. Neither the subjects nor the investigators at the U.S. Army Research Institute of Environmental Medicine were aware of the identity and size of the saline and reinfusion groups.

The maximal aerobic power and heat stress tests were conducted at the U.S. Army Research Institute of Environmental Medicine. Each subject's maximal aerobic power was determined by a progressive intensity, continuous effort treadmill test. The warm-up bout consisted of four min of walking (1.56 $m \cdot s^{-1}$) at a 4% treadmill grade. The subjects then ran (3.13 $m \cdot s^{-1}$) continuously at an initial grade of 5% with 2-1/2% increments every two min. Established criteria were employed for determination of maximal oxygen uptake (28). These tests were conducted in a comfortable (20°C ambient temperature, 40% relative humidity) environment.

The heat stress tests (HSTs) were conducted in a hot (35°C ambient temperature, 45% relative humidity) environment. This environment was selected to enable both insensible as well as some sensible heat exchange. Each HST was 120 min (two repeats of 15 min rest and 45 min exercise) unless

predetermined end points of a heart rate > 180 beats·min^{-1} for five min, a rectal temperature > 39.5°C, an esophageal temperature > 39.2°C, or physical exhaustion were reached. During exercise, subjects walked (1.56 m·s^{-1}) on an inclined (6% grade) treadmill, and during the rest periods they were weighed and rehydrated with spring water to maintain their initial body weight (i.e. euhydration). The subjects wore only shorts and tennis shoes. At least 10-days separated the pre- and post-infusion HSTs to minimize any partial acclimation from the initial heat exposure.

Measurements. Electrocardiogram was obtained with chest electrodes (CM5 placement) and radiotelemetered to an oscilloscope-cardiotachometer unit (Hewlett-Packard). During the maximal aerobic power tests, an automated system (Sensormedics Horizon MMC) was used to measure oxygen uptake. During the HSTs, the respiratory gases were collected in 150-liter Douglas bags. The volume of expired gases was measured with a Tissot gasometer, and the O_2 and CO_2 concentrations were measured with an electrochemical O_2 analyzer (Applied Electrochemistry S-3A) and an infrared CO_2 analyzer (Beckman LB-2), respectively.

During the HSTs, core temperature measurements were obtained from both the rectum and esophagus. Rectal temperature was measured from a thermistor inserted ~10 cm beyond the anal sphincter and esophageal temperature was measured from a thermistor placed in a catheter at heart level. Unfortunately, two subjects, from the saline group, were unable to swallow the esophageal thermistor. Skin temperatures were obtained with a three-point thermocouple skin harness (chest, calf, and forearm), and mean weighted skin temperature was calculated (5). The unventilated dew point temperature of the upper arm was continually measured by an automatic sensor (15). Body weights were

determined on a K-120 Sauter precision electronic balance (accuracy ± 10 g). Total body sweat rates ($\dot{m}_{sw}$) were calculated from nude body weight loss adjusted for water intake and urine output. Total body heat storage (16) as well as arm sensible (radiative and convective, R+C) and arm evaporative (evaporation from skin, E_{sk}) heat loss were calculated as previously described (14).

Venous blood samples were collected from an indwelling Teflon catheter placed within a superficial forearm vein. Patency was maintained with heparinized saline; the catheter (2-ml of dead space) was flushed with 4-ml of blood before each 5-ml sample was obtained. Resting blood samples were obtained while all the subjects stood (for 20-min prior to sampling) in the antechamber (20°C ambient temperature, 40% relative humidity), and exercise blood samples were obtained 30-min into each exercise bout while the subjects continued to walk. Triplicate measurements were made for all blood variables. Automated systems were used for hemoglobin (Hemoglobinometer, Coulter Electronics) and plasma lactate (Model 23 Lactate Analyzer, YSI). Plasma osmolality was measured with freezing point depression (Osmette A, Precision Systems) and plasma protein concentration was quantitated with a refractometer (American Optical). The percent change in plasma volume from rest to exercise was calculated from the appropriate hemoglobin and hematocrit values (8). Red cell volume (RCV) and plasma volume (PV) at rest were measured by the radioactively labelled chromium (^{51}Cr) and iodine labelled albumin (^{125}I) methods (32), respectively. The plasma volumes during exercise were calculated by adjusting the measured plasma volume at rest by the appropriate relative percent change in plasma volume. The F-cell ratio (6) was calculated from the ratio of overall hematocrit (H_O) to the peripheral venous hematocrit (not

corrected for trapped plasma). The overall hematocrit was calculated as:

$$H_O = \frac{RCV}{RCV + PV}$$

Statistical Analyses. Means, standard deviations, simple regression, and repeated measures analyses of variance followed by Bonferroni (11) procedures were used. Statistical significance was tested at the $P < 0.05$ level. It was not our intent to make direct comparisons between the saline and reinfusion groups; therefore, an unbalanced experimental design was selected. The saline group was used to control for the influence of partial heat acclimation during the study as well as to provide an index of pre- to post- infusion measurement variability.

RESULTS

Infusion. Table 1 provides the subjects' resting hematological measurements for pre- and post-infusion. For the reinfusion group, there was an increased ($P < 0.05$) red cell volume by 11%, hemoglobin by 10% and hematocrit by 12% from pre- to post-reinfusion. Figure 1 indicates that the increased red cell volume (222 ml) was associated ($r = -0.72$; $P = 0.07$) with a reduced plasma volume (265 ml) from pre-to post-reinfusion. Neither blood volume nor F-cell ratio was altered by reinfusion. For the reinfusion group, no differences were found for red cell 2,3 DPG, 15.3 ± 2.3 to 14.4 ± 2.0 mmol·g Hb^{-1}; ATP, 4.2 ± 0.5 to 4.2 ± 0.8 mmol·g Hb^{-1}; and P_{50}, 27 ± 2 to 27 ± 1 mmHg from pre- to post-reinfusion.

For the saline group, there was a decreased ($P < 0.05$) red cell volume by 3%, plasma volume by 4% and blood volume by 4% from pre-to post-infusion. Hemoglobin, hematocrit and F-cell ratio were not altered by infusion. For the saline group, no differences were found for red cell 2,3 DPG, 13.6 ± 2.3 to

14.4 ± 1.6 mmol·gHb^{-1}; ATP, 3.5 ± 0.4 to 3.5 ± 0.4 mmol·gHb^{-1}; and P_{50}, 27 ± 1 to 27 ± 1 mmHg from pre- to post-infusion.

Maximal Exercise. Table 2 provides the subjects' physiological responses to maximal effort exercise. For the reinfusion group, maximal oxygen uptake increased ($P < 0.05$) by 11% from pre- to post-reinfusion. Neither heart rate nor ventilatory equivalent of oxygen were altered by reinfusion. For the saline group, heart rate, ventilatory equivalent of oxygen and maximal oxygen uptake were not altered by infusion.

Heat Stress Tests. All nine subjects completed (120-min) each HST. Table 3 provides the subjects' physiological responses to the HSTs. For the reinfusion group, metabolic rate and mean skin temperature were not altered, but final exercise heart rate was reduced ($P < 0.05$) from pre- to post-reinfusion. No differences were found for final exercise rectal temperature (38.7 ± 0.6 to 38.5 ± 0.2°C) nor final exercise esophageal temperature (38.3 ± 0.5 to 38.0 ± 0.1°C) from pre- to post-reinfusion. Heat storage as calculated from rectal temperature changes was lower ($P < 0.05$) for the first, but not the second exercise bout during the post-reinfusion HSTs. Heat storage as calculated from esophageal temperature changes was lower ($P = 0.06$) post-reinfusion and is depicted in Figure 2. It can be noted that eleven of twelve observations (six subjects x two exercise bouts) demonstrated lower values post-reinfusion. Table 4 provides the subjects' steady-state heat exchange during the HSTs. For the reinfusion group, total body sweat rate, arm E_{sk}, and arm (R+C) were not altered from pre-to post-reinfusion.

For the reinfusion group, plasma volume was decreased from the pre- to post-reinfusion HSTs. Figure 3 presents the reinfusion group's plasma volume and percent change in plasma volume from rest to exercise during the HSTs. The

percent change in plasma volume from rest to exercise was greater ($P < 0.01$) post-reinfusion, but the absolute fluid volume that moved from the interstitial to the intravascular space was nearly identical (~190 ml) pre- and post-reinfusion. Table 5 presents the plasma osmolality, plasma lactate, plasma protein content and total circulating protein during the HSTs. For the reinfusion group, plasma osmolality, plasma lactate and plasma protein content were not altered from pre- to post-reinfusion. However, total circulating protein, was lower ($P < 0.01$) post-reinfusion.

For the saline group, metabolic rate, heart rate, mean skin temperature and heat storage as calculated from rectal temperature were not altered by infusion (Table 3). Also, a difference was not found for final exercise rectal temperature (38.5 ± 0.1 and 38.4 ± 0.1°C) from the pre- to post-infusion HSTs. Esophageal temperature is not reported since it was measured in only one subject from the saline group. For the saline group, arm (R+C), arm E_{sk} and total body sweat rate were not altered by infusion (Table 4). Neither plasma volume nor percent change in plasma volume from rest to exercise was altered by infusion. Likewise, differences were not found for plasma osmolality, plasma lactate, plasma protein content nor total circulating protein from the pre- to post-infusion HSTs (Table 5).

DISCUSSION

It has been reported that several recent Summer Olympic medal winners have used blood infusions (homologous and autologous) or "blood doping" as an ergogenic aid. These athletes participated in endurance events which required high maximal aerobic power and made considerable thermoregulatory demands for heat dissipation. Although we do not advocate the use of "blood doping" as

an ergogenic aid for athletic competition, autologous erythrocyte infusion provides a powerful tool to further our understanding of physiological control mechanisms in response to exercise-heat stress. While blood doping for athletic competition is unsanctioned and considered unethical, it can increase maximal aerobic power provided that specific blood handling and infusion procedures are used (12, 13). These procedures are that: (a) the infused autologous erythrocytes represent the product of two blood units; (b) the erythrocytes are freeze preserved; and (c) the infusion does not precede re-establishment of normocythemia. By employing these techniques, our subjects had an ~11% increment for their oxygen carrying capacity and subsequent maximal aerobic power. The magnitude of these increases are consistent with those reported by others employing similar procedures (4, 17, 18, 19, 29).

Our data indicate that acute erythrocythemia results in an adaptive reduction in plasma volume (Fig. 1). The reinfused subjects had an increased red cell volume and decreased plasma volume of 222 ml and 265 ml, respectively. Interestingly, the saline group manifested a decreased red cell volume and plasma volume from pre- to post-infusion. This observation raises the possibility that systematically decreased post-reinfusion measurements may have masked a slight increase in blood volume for the reinfusion group. Bentley and Lewis (1) independently measured red cell volume (^{51}Cr) and plasma volume (^{125}I) in 130 patients with polycythemia and a variety of hematological disorders. They found a positive linear relationship ($P < 0.001$) between venous hematocrit and total blood volume in patients with venous hematocrits of greater than 50%, but in patients with lower hematocrits no relationship was found between these variables. Bentley and Lewis (1) also observed that for individuals with venous hematocrits of ~40% or less there is a inverse ($r = -0.75$; $P < 0.001$) relationship

between venous hematocrit and plasma volume. Our subjects had initial venous hematocrits of 42% (range 37 to 45%); therefore, the compensatory reduction in plasma volume for the increased red cell volume ($r = -0.72$) was consistent with the clinical data from Bentley and Lewis (1). It seems possible that the plasma volume responses to erythrocyte infusion may somehow be dependent on the initial pre-infusion hematocrit.

Valeri and Altschule (32) have reported that a red cell transfusion can increase plasma volume in trauma patients. As erythrocytes do not exert an in vitro oncotic pressure, they reported that the expanded plasma volume from red cell transfusion was mediated by a mobilization of interstitial albumin into the intravascular space (31, 32, 33). Of note is that their protein-mediated plasma volume expansion in trauma patients is nearly identical to that mechanism contributing to heat acclimation hypervolemia (26). Interestingly, the patients were wounded servicemen who had been transported from Southeast Asia usually within the preceding two weeks. These individuals were probably heat acclimated from living in a warm climate. Our subjects were unacclimated to heat; in fact, they had participated in cold weather training before and during the study. Perhaps, if heat acclimated subjects were reinfused, their greater availability of extravascular protein (26) might have allowed a plasma volume expansion.

During the post-reinfusion HSTs, the reinfused subjects had a reduced (~7%) plasma volume with the same blood volume as in the pre-reinfusion HSTs. This reduced plasma volume did not affect the absolute magnitude (~190 ml) of hemodilution resulting from the transition from rest to exercise. Therefore, plasma volume per se does not exert an effect independent of blood volume on vascular fluid shifts during exercise-heat stress. This observation is of interest,

but not surprising since the transcapillary osmotic, oncotic and probably hydrostatic pressures were not different from pre- to post-reinfusion. On the other hand, several investigators (10, 17) have shown that manipulation of plasma volume to change blood volume will alter vascular fluid shifts during exercise. Finally, the approximate 7% reduction in plasma volume is similar in magnitude to the reduction associated with the hypovolemia during moderate hypohydration (25). As a result, it might be interesting to examine the hematological responses of reinfused subjects who had the additional challenge of hypohydration during exercise-heat stress.

We are the first to examine the influence of acute erythrocythemia on thermoregulation during exercise-heat stress. Our data indicate that erythrocythemia provides a small thermoregulatory advantage for euhydrated non heat-acclimated individuals. Heat storage values, as calculated from esophageal temperatures, were lower post-reinfusion for 11 of 12 observations. Unfortunately, two subjects could not swallow the esophageal catheter, and because of the double blind design we did not realize that both were saline subjects. As a result, we do not have these data for the saline group. Heat storage values as calculated from rectal temperature were obtained for both groups and were different for the reinfusion group only during the first exercise bout. Rectal temperature measurements are slower to respond than esophageal temperature changes (21, 23) and therefore will not always provide similar values. It remains unclear as to what degree insensible and/or sensible heat exchange were independently responsible for the reduced heat storage after erythrocyte reinfusion. Neither total body sweat rate nor steady-state arm E_{sk} values differed between the two conditions. Likewise, the steady-state arm (R+C) data did not show a difference, but this measurement may not have been

sufficiently sensitive to detect such small differences. Alternatively, both insensible and sensible heat loss from the arm may not always follow changes from other body regions (10,23). Finally, the improved effector responses for heat loss may have occurred at the onset of exercise (lower threshold responses) and therefore would not be evident in the steady-state measurements.

We can hypothesize several potential physiological mechanisms for improved sensible heat exchange after erythrocyte infusion. One possible explanation for improved sensible heat loss is that the elevated arterial oxygen content allowed a reduced skeletal muscle blood flow and, thus increased cutaneous blood flow at a given cardiac output during submaximal exercise. Welch et al. (35) found that a 10% increase in arterial oxygen content during hyperoxia in humans resulted in a similar decrease in muscle blood flow during submaximal exercise. Likewise, several studies using dogs have reported similar findings of reduced skeletal muscle blood flow when arterial oxygen content was elevated by hyperoxia during submaximal exercise (34, 36). Another possible explanation for an improved sensible heat loss is that erythrocythemia may lower cardiac output during submaximal exercise. A lower cardiac output might require a smaller central blood volume, and thereby reduce venoconstrictor tone (2, 3) and allow a larger cutaneous blood volume. This would increase blood residence time in the skin and allow more effective heat transfer from blood to skin. Several investigators (9, 18, 27) report that an increased arterial oxygen content reduced the cardiac output response to submaximal exercise conducted in the absence of thermal strain. Robertson et al. (18) measured the cardiac output responses of nine women during submaximal exercise ($\dot{V}O_2$, 1.8 $\ell \cdot min^{-1}$) in a comfortable environment both before and after erythrocyte reinfusion. After reinfusion, their subjects had a 16% increase in hemoglobin and an 11%

reduction in cardiac output. Another recent study (27) reported that acute erythrocythemia will reduce the cardiac output response of dogs during submaximal exercise. Consistent with these erythrocythemia studies, Ekblom et al. (9) found that breathing hyperoxic gases (50% oxygen) can reduce cardiac output responses during submaximal exercise. In opposition, Thomson et al. (29) found that erythrocythemia (12% increase in hemoglobin) did not alter four subjects' cardiac output response to submaximal exercise.

Therefore, we have proposed two physiological mechanisms by which erythrocythemia could possibly improve sensible heat exchange and thereby reduce heat storage. The increased arterial oxygen content may have enabled a reduced skeletal muscle blood flow during submaximal exercise (34, 35, 36,). If the exercise cardiac output response was not altered, then an increased cutaneous blood flow would be possible during exercise-heat stress. If the cardiac output response was decreased by erythrocythemia, then the reduced venoconstriction of the cutaneous vasculature (2, 3) would allow a greater cutaneous blood volume and more effective heat transfer.

Our data indicate several new findings concerning acute erythrocythemia: (1) the increased red cell volume was associated with a reduction in plasma volume to maintain the same blood volume as during the pre-infusion measurements; (2) erythrocythemia reduced total circulating protein, but did not alter F-cell ratio, plasma osmolality, plasma protein content, or plasma lactate at rest or exercise-heat stress; (3) erythrocythemia did not change the volume of fluid entering the intravascular space from rest to exercise-heat stress; and (4) erythrocythemia reduced heat storage during exercise-heat stress. These results should not be generalized beyond euhydrated subjects who are unacclimated to heat.

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Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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Table 1. Influence of red cell or saline infusion on hematological variables at rest.

		Red Cell Volume (ℓ)	Plasma Volume (ℓ)	Blood Volume (ℓ)	Hemoglobin ($g \cdot dl^{-1}$)	Venous Hematocrit	F-cell ($H_O \cdot H_V^{-1}$)
REINFUSION (n=6)							
Pre-	$\bar{X}$	2.079	3.674	5.753	13.9	42	0.89
	SD	0.258	0.285	0.425	1.1	3	0.06
Post-	$\bar{X}$	2.301	3.409	5.710	15.3	47	0.87
	SD	0.234	0.238	0.451	1.1	2	0.03
	% Δ	11	-7	ND	10	12	ND
SALINE (n=3)							
Pre-	$\bar{X}$	2.158	3.463	5.621	14.9	44	0.88
	SD	0.358	0.661	1.015	0.6	2	0.01
Post-	$\bar{X}$	2.093	3.311	5.403	14.9	44	0.89
	SD	0.335	0.625	0.954	0.8	2	0.02
	% Δ	-3	-4	-4	ND	ND	ND

ND is not statistically different, H_O is overall hematocrit and H_V is venous hematocrit.

TABLE 2. Influence of red cell or saline infusion on physiological responses to maximal exercise.

	Heart Rate ($b \cdot min^{-1}$)	Ventilatory Equivalent of Oxygen ($\dot{V}E \cdot \dot{V}O_2^{-1}$)	Maximal Oxygen Uptake ($\ell \cdot min^{-1}$)	Maximal Oxygen Uptake ($ml \cdot kg^{-1} \cdot min^{-1}$)
REINFUSION (n=6)				
Pre- $\bar{X}$	190	37	4.280	54
SD	7	2	0.215	5
Post- $\bar{X}$	185	34	4.753	60
SD	9	3	0.426	6
% Δ	ND	ND	11%	11%
SALINE (n=3)				
Pre- $\bar{X}$	197	35	4.670	56
SD	2	5	1.073	4
Post- $\bar{X}$	193	35	4.714	57
SD	5	4	0.837	4
% Δ	ND	ND	ND	ND

ND is not statistically different.

TABLE 3. Influence of red cell or saline infusion on physiological measurements during the Heat Stress (35°C, 45% rh) Exercise Tests.

		Metabolic Rate ($W \cdot m^{-2}$)	Heart Rate ($b \cdot min^{-1}$)		Mean Skin Temperature (°C)		ΔS, Tre ($W \cdot m^{-2}$)		ΔS, Tes ($W \cdot m^{-2}$)	
			Ex-1	Ex-2	Ex-1	Ex-2	Ex-1	Ex-2	Ex-1	Ex-2
REINFUSION (n=6)										
Pre-	$\bar{X}$	358	139	145	33.5	33.3	72	29	65	72
	SD	25	15	19	0.4	0.5	11	11	11	39
Post-	$\bar{X}$	349	132	141	33.9	34.0	63	29	55	43
	SD	28	15	13	0.9	0.8	9	5	15	5
	Δ	ND	7	4	ND	ND	9	ND	10	29
SALINE (n=3)										
Pre-	$\bar{X}$	352	144	151	33.2	33.2	58	58	--	--
	SD	50	6	7	0.6	0.7	1	27	--	--
Post-	$\bar{X}$	352	145	158	33.6	34.0	63	67	--	--
	SD	41	2	9	0.4	0.7	19	41	--	--
	Δ	ND	ND	ND	ND	ND	ND	ND		

ΔS is heat storage, Tre is rectal temperature, Tes is esophageal temperature,
ND is not statistically different, Ex-1 and Ex-2 are exercise bouts 1 and 2, respectively.

TABLE 4. Influence of red cell or saline infusion on heat exchange measurements during the Heat Stress (35°C, 45% rh) Exercise Tests.

		Arm (R + C) ($W \cdot m^{-2}$)		Arm Esk ($W \cdot m^{-2}$)		Total Body Sweat Rate ($g \cdot m^{-2} \cdot h^{-1}$)	
		Ex-1	Ex-2	Ex-1	Ex-2	Ex-1	Ex-2
REINFUSION (n=6)							
Pre-	$\bar{X}$	-12.0	-0.6	240	375	386	581
	SD	12.0	8.0	34	29	52	46
Post-	$\bar{X}$	-14.9	-10.1	240	359	384	559
	SD	6.2	5.9	38	32	58	49
	Δ	ND	ND	ND	ND	ND	ND
SALINE (n=3)							
Pre-	$\bar{X}$	-23.9	-18.4	263	335	420	524
	SD	8.2	7.5	46	25	72	36
Post-	$\bar{X}$	-17.8	-12.6	258	330	411	559
	SD	3.0	8.8	11	79	20	59
	Δ	ND	ND	ND	ND	ND	ND

ND is not statistically different, Ex-1 and Ex-2 are exercise bouts 1 and 2, respectively. Arm sensible (radiative and convective, R+C) and insensible (evaporative from skin, E_{sk}) heat exchange values represent steady-state (final exercise) values.

TABLE 5. Influence of red cell or saline infusion on plasma osmolality, plasma lactate, plasma protein and total circulating protein during the Heat Stress (35°C, 45% rh) Exercise Tests.

		Osmolality ($mosmol \cdot kg^{-1}$)			Lactate ($mmol \cdot \ell^{-1}$)			Protein Content ($g \cdot dl^{-1}$)			Total Circulating Protein (g)		
		Rest	Ex-1	Ex-2	Rest	Ex-2	Ex-2	Rest	Ex-1	Ex-2	Rest	Ex-1	Ex-2
REINFUSION (n=6)													
Pre-	$\bar{X}$	285	288	289	1.1	1.3	1.1	8.1	7.8	8.0	299	298	308
	SD	2	2	3	0.3	0.3	0.5	0.7	0.5	0.5	34	37	29
Post-	$\bar{X}$	287	288	289	1.2	1.5	1.4	8.3	7.8	8.0	284	283	287
	SD	3	3	4	0.3	0.6	0.4	0.6	0.5	0.5	36	36	36
	Δ	ND	ND	ND	ND	ND	ND	ND	ND	ND	15	15	21
SALINE (n=3)													
Pre-	$\bar{X}$	286	287	289	1.7	1.2	1.3	7.9	7.7	7.9	274	267	275
	SD	0	6	4	0.2	0.1	0.1	0.3	0.2	0.1	48	58	58
Post-	$\bar{X}$	286	291	288	1.2	1.4	1.3	8.2	7.7	7.9	272	269	272
	SD	2	3	5	0.3	0.1	0.2	0.3	0.2	0.1	58	53	56
	Δ	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

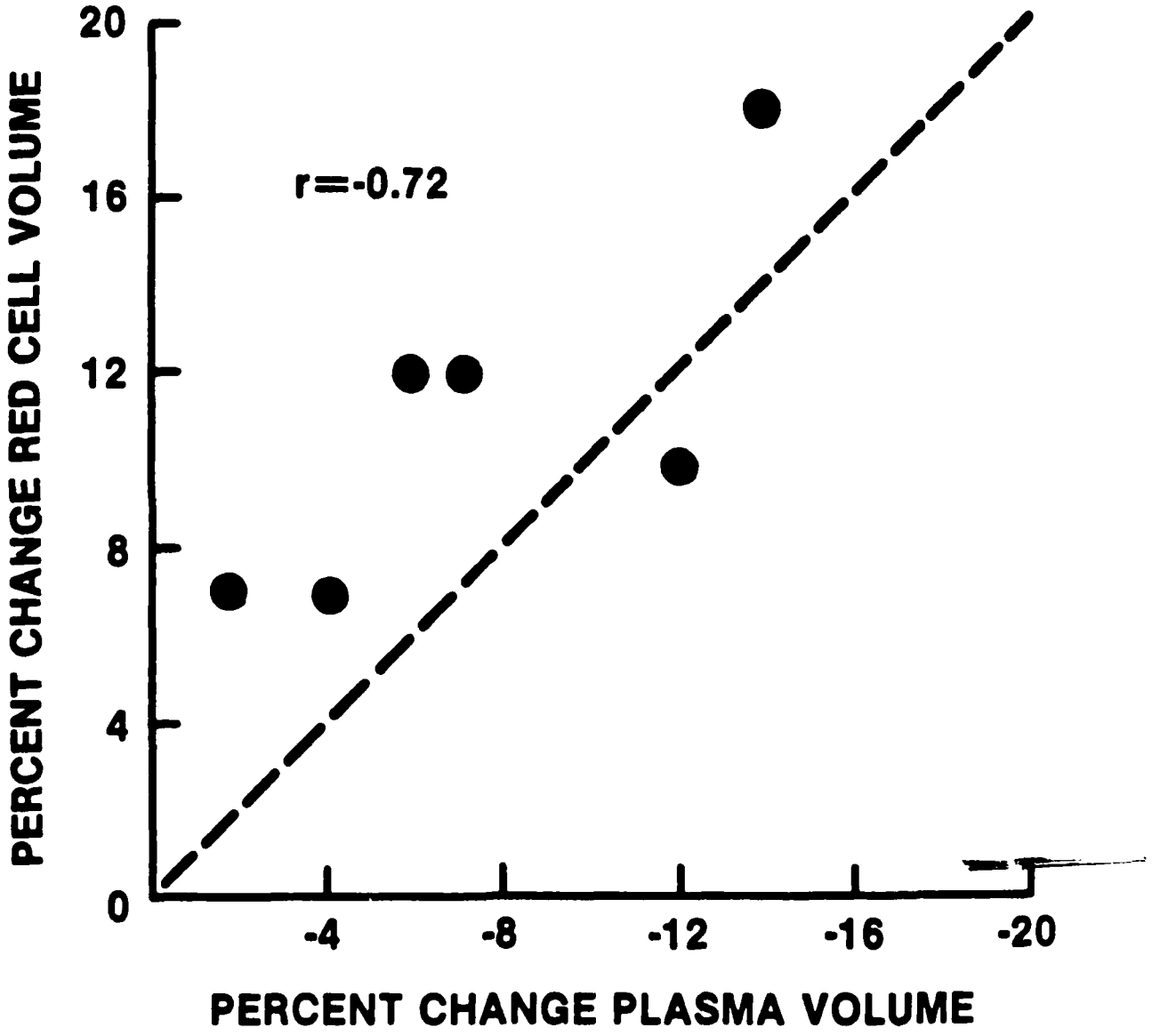
ND is not statistically different, Ex-1 and Ex-2 are exercise bouts 1 and 2, respectively.

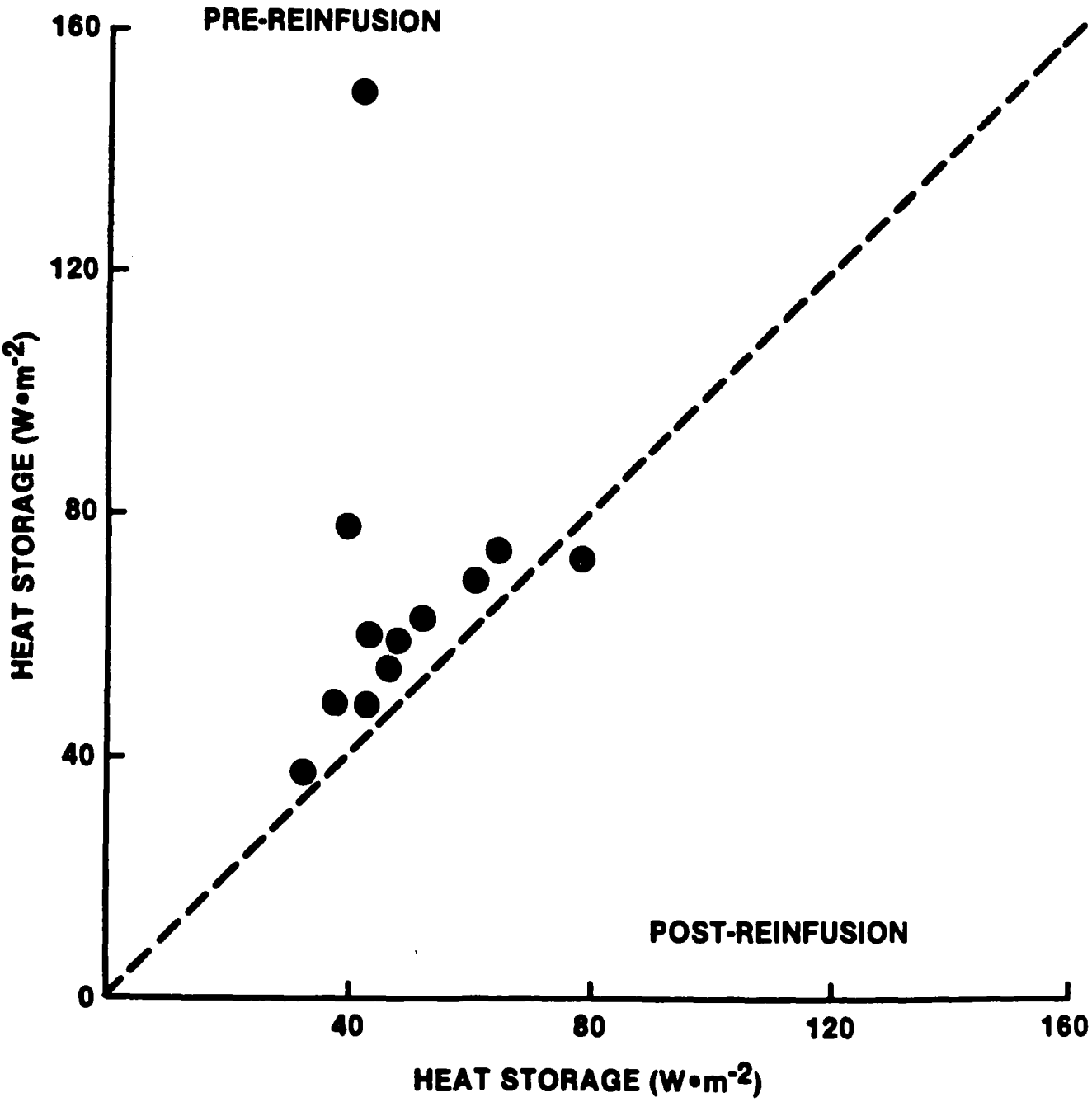
FIGURE LEGENDS

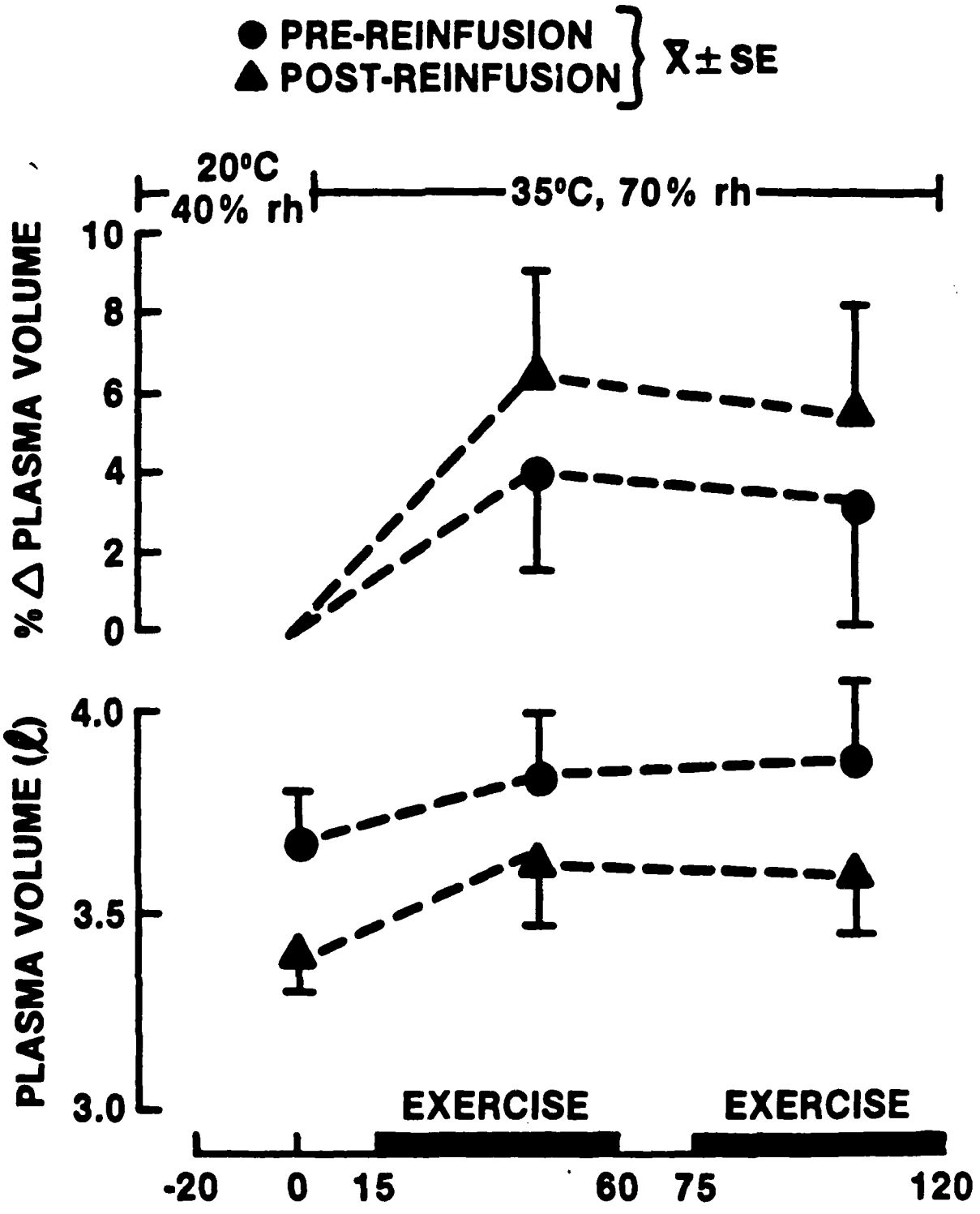
Fig.1. The relationship between the percent change in red cell volume to the percent change in plasma volume after erythrocyte reinfusion.

Fig.2. Individual data plots of pre- to post- reinfusion values for heat storage (calculated from esophageal temperature) during the Heat Stress Tests.

Fig.3. Plasma volume and the percent change in plasma volume from rest during the pre- and post- reinfusion Heat Stress Tests.


20
16
12
8
4
0
r=-0.72
PERCENT CHANGE RED CELL VOLUME
-4
-8
-12
-16
-20
PERCENT CHANGE PLASMA VOLUME


PRE-REINFUSION
160
120
80
40
0
HEAT STORAGE (W•m-2)
POST-REINFUSION
40
80
120
160
HEAT STORAGE (W•m-2)


● PRE-REINFUSION
▲ POST-REINFUSION
X̄ ± SE
20°C
40% rh
35°C, 70% rh
% Δ PLASMA VOLUME
10
8
6
4
2
0
PLASMA VOLUME (ℓ)
4.0
3.5
3.0
EXERCISE
EXERCISE
-20
0
15
60
75
120

DTIC

FILMED

4-86

END